RESEARCH PAPER

Impact of disturbance from roadworks on *Pteleopsis suberosa* regeneration in roadside environments in Burkina Faso, West Africa

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Abstract: The seedling population structure of *Pteleopsis suberosa* and their regeneration mechanisms were investigated in four roadside environments (graded, adjacent, intermediate and ungraded areas) along paved and unpaved roads in West Africa. A total of 203 quadrats of 2 m × 5 m in size were surveyed and placed along transects parallel to the roads. Within each quadrat, the total number of seedlings and the number of living shoots per seedling base were recorded. Regeneration mechanisms were determined by assessing basal and aerial sprouts and excavating the root systems below ground level. The results show that the total seedling density and the densities of single- and multi-stemmed individuals varied significantly ($p < 0.05$) among the four roadside environments. However, all seedlings were produced asexually; root suckers were predominant (98%) compared to water sprout (1%) and coppices (less than 1%). This study demonstrates that an intermediate level of soil disturbance from grading along paved and unpaved roads may stimulate *P. suberosa* regeneration by root suckering. Road type (paved and unpaved) did not affect seedling density, but was a highly significant variable in relation to the coppicing ability of *P. suberosa* populations in roadside sites. In conclusion, *P. suberosa* is a disturbance-tolerant species which can proliferate mainly by root suckering after roadwork disturbance.

Keywords: *Pteleopsis suberosa*; roadwork disturbance, seedling, regeneration, root sucker

Introduction

Roads make vital contributions to civilization (Gucinski et al. 2001), but their effects may be somewhat arbitrarily beneficial and detrimental. The main beneficial effects are related to access, and include facilitating transportation, the harvest of forest products, grazing, recreation, land management and access to private

holdings. Hence, they can greatly help local communities to meet all their needs with respect to critical subsistence and cultural values (Spooner and Smallbone 2009). Non-access-related benefits include the creation of edge habitats and fire breaks and the creation of jobs associated with road building and maintenance (Lugo and Gucinski 2000). However, although road construction is ultimately beneficial for socio-economic development, the construction and operation of roads may cause a variety of ecological impacts that are raising serious concerns among ecologists, conservationists and the general public (Karim and Mallik 2008; Liu et al. 2008). Roads can have both direct and indirect impacts on the surrounding vegetation. They may cause local changes in plant communities, landscape-level changes in forest connectivity, and alterations in the spatial patterns of adjacent ecosystems. Notably, "dissection" by roads (Forman 1995) creates edges that can severely affect the biotic and abiotic environments and hence drive changes in vegetation structure and floristics (Karim and Mallik 2008). Furthermore, disturbances resulting from roadworks and related operations can affect vegetation communities both chemically and physically by increasing levels of chemical pollutants (Forman and Alexander, 1998); can promote the transport of non-native and disturbance-tolerant species (Watkins et al. 2003); can increase disturbance from

humans (Forman and Alexander 1998); and can harm other wildlife by injury and road-kill (Rhim et al. 2003).

The most noticeable effects of roads occur within 10−15 m of the roadside (Watkins et al. 2003; Hansen and Clevenger 2005). The most obvious effects of road construction are soil disturbance, and the creation of distinct sites for plant establishment in roadside habitats as a result of specific micro-topography, microclimate, soil moisture, light availability and substrate properties (Forman 2004; Karim and Mallik 2008). Physical impacts of roads include the acceleration of erosion from road surfaces, alteration of soil surface water flows and the timing of peak flows, increased landslides and loss of soil productivity (Forman 2004). Heavy machinery used to construct roads and infrastructure corridors can cause substrate compaction (Forman, 1998). In addition, graders remove the topsoil to varying depths and it is then mixed together with soils with diverse physical and chemical characteristics from neighboring sites and/or soils trucked in from distant locations.

However, roadsides may also act as reservoirs of biological diversity via the accumulation and deposition of seed banks mediated by vehicle-caused air turbulence or other favorable roadside conditions (Lonsdale and Lane 1994). Roadside environments also provide important refuges for isolated populations of many plant species. In areas ecologically affected by a road system, ponds, ditches, berms and roadsides all offer diverse, patchy biotopes as a result of their varying widths, sunny and shaded conditions, slope angles and exposure (Forman and Alexander 1998). Disturbances from road construction can have negative impacts by fragmenting plant populations, but some native species with well-adapted mechanisms for reproduction, dispersal and establishment may prosper under such regimes (Clarke 1991). Vegetation may also recover rapidly at road edges because the side-cast topsoil may retain regeneration materials (i.e. buried seeds) and the altered road-edge microclimate, with increased light availability, higher soil surface temperature and increased moisture stress, particularly favors disturbance-adapted plants including edge and gap specialists (Spooner, 2005). On the other hand, roadside recovery and regeneration may be substantially retarded in some cases due to substrate compaction by machinery (Malmer and Grip 1990) and lack of on-site plant propagules after topsoil removal. Seed limitation may also affect regeneration at the roadside, partly because of the removal of seed-producing trees, or the creation of unsuitable regeneration-sites (Spooner et al. 2004). Since ecological studies of roads have usually focused on their deleterious effects, Lugo and Gucinski (2000) were prompted to pose the question "are all effects negative?" To address this question, in-depth studies are required of both positive and negative edge effects on regeneration and recovery in roadside environments, along with the associated processes, to elucidate more fully the auto-ecological features of plants that can, and those that cannot, adapt to altered roadside habitats. Such studies would also aid decision-making when planning conservation strategies, monitoring, and restoration.

In many Sub-Saharan African countries, the road network is currently undergoing extensive expansion and upgrading, at both national and regional scales (World Bank 2003). In Burkina Faso alone, 15 000 km of roads are classified as part of the national road network. However, the ecological effects of this expansion on the ecosystems and the landscapes that new roads bisect have received little attention, as indicated by the scarcity of empirical research. The present study contributes to an emerging subject by providing further evidence that roads are affecting ecosystem components, processes and structures (Coffin, 2007), focusing on the effects of roadworks on *Pteleopsis suberosa* as a model species. *P. suberosa* is a 4−7 m high shrub, present in Guinean and Sudanian regions. In the Sudanian region, it grows in deciduous woodland and wooded grassland on clay soils, sandstone and sandy or rocky soils. The species has immense socioeconomic value for local inhabitants as fuel-wood and livestock feed during the bridging period (Arbonnier 2002) and as a source of ingredients for pharmaceuticals (Germano et al. 2008).

The principal questions addressed in the study are: (1) Do *P. suberosa* seedling populations in road environments differ along grading disturbance levels? (2) How do disturbances associated with the construction of paved and unpaved roads affect the structure and regeneration mechanisms of *P. suberosa* populations? We hypothesized that *P. suberosa* populations along roadside habitats would display zonation, reflecting the zonation of microhabitats created by road construction. We further hypothesized that the colonization of these microhabitats is dependent upon the presence of suitable adaptive regeneration traits.

Methods

Site description

This study was carried out in Western Burkina Faso (latitudes 11°15′−12°50′N and longitudes 2°30′−4°00W). In order to examine the range of roadside habitats, four roadside environments: graded, adjacent, intermediate and ungraded areas were sampled, alongside two paved national and two unpaved county roads. The national roads run between Pâ and Boromo, and Dédougou and Ouarkoye, while the county roads are situated between Ouarkoye and Kona and between Bouan and Ouakara (Fig. 1). The construction and reconstruction work on the roads chosen for sampling was completed in 2004. Phytogeographically, the study site is situated in the Sudanian regional centre of endemism in the south Sudanian Zone, and the vegetation is dry forests composed mainly of savanna and open woodlands (Fontes and Guinko 1995). The unimodal rainy season period lasts from May to October. The mean annual rainfall at the study sites ranges from 700 mm to 900 mm. The average annual temperature is 27.1°C, with a maximum average monthly temperature of 31.7°C in April and a minimum average monthly temperature of 25.3°C in August. The most frequently encountered soils are Lixisols or poorly leached ferruginous tropical soils with overlying sandy, sandy-clayey or clayey-sandy material (Driessen et al. 2001). These soils are representative of large tracts of the Sudanian Zone in Burkina Faso.
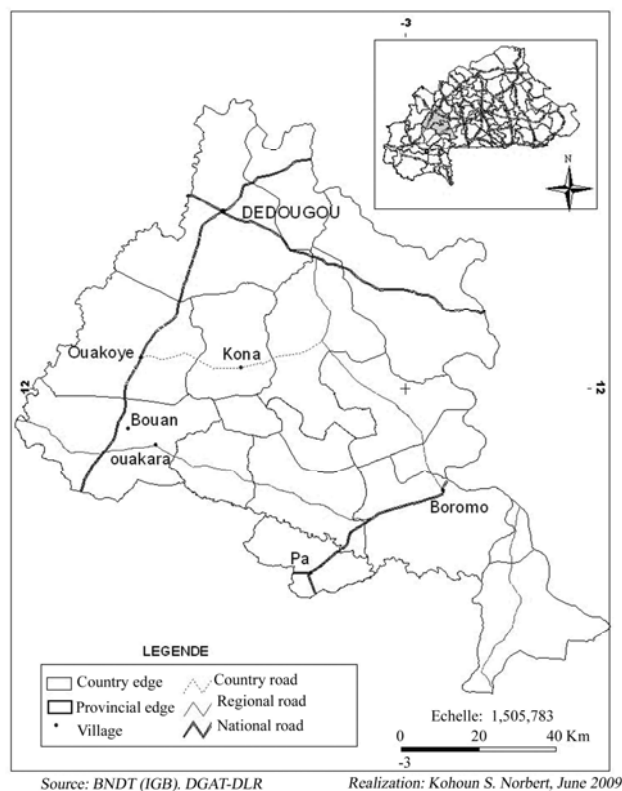
**Fig. 1 Road networks of Burkina Faso with the location of the study sites**

Data collection

We surveyed seedlings of *P. suberosa* in the four roadside environments (graded, adjacent, intermediate and ungraded areas; see below for definitions) using quadrats measuring 2 m × 5 m along four parallel transects containing 203 populations of *P. suberosa*. In this survey, a population is defined as any number of individuals isolated by at least 250 m from other populations of the same species (Oostermeijer et al. 1996). The starting point of the first transect was set 5 m from the edge of the road impact area, and thereafter the four parallel transects were located every 10 m, moving away from the edge. The first transect was located in the graded area, the second was located 10 m from the graded area (hereafter the adjacent area), the third was located 20 m from the graded area (hereafter the intermediate area) and the fourth (control) was located in the ungraded area 30 m from the graded area (Fig. 2). The grading activities were nested within the two road types, paved and unpaved. In both cases, grading was conducted parallel to the road, extending into the adjacent area. Grading removed the upper 1−5 cm of topsoil and all vegetation, and the depth of grading decreased by half from the graded to the adjacent area. The inside edge of the natural vegetation, (considered here as being represented by the intermediate area) was part of the area cleared before road construction. The natural vegetation (considered as being represented by the control) was not subject to any disturbance during road construction work. A total of 203 quadrats (92 quadrats along unpaved roads and 111 along the

paved roads), one in each population, were laid out for data collection. The number of quadrats sampled in each roadside environment is given in Table 1. The unbalanced replication between roadside environments was mainly due to the presence of cropland at some locations along the roads.

Table 1. Number of quadrats for each roadside environment surveyed

Road type	Roadside environments				
	Graded	Adjacent	Intermediate	Ungraded	Total
Paved	36	32	22	21	111
Unpaved	25	16	21	30	92
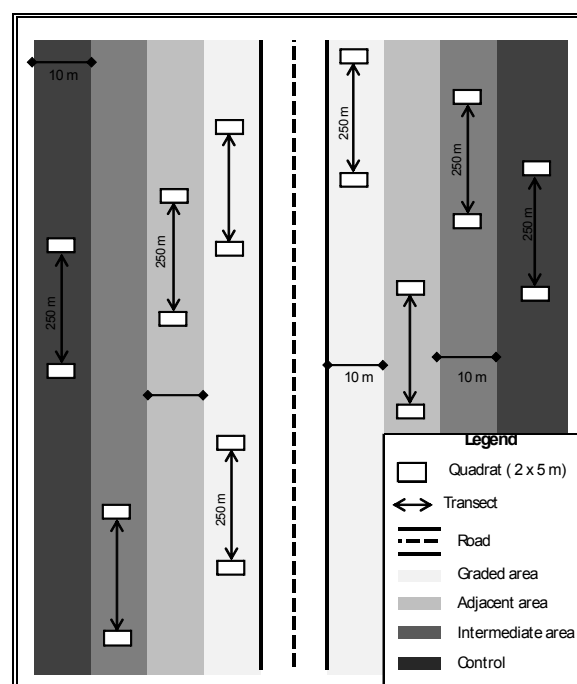
Fig. 2 A diagram representing the vegetation sampling design along the roads

Table 2. Typical characteristics of the different regeneration mechanisms of *Pteleopsis suberosa*

Regeneration mechanism	Characteristics
True seedling	Seedling originated from seed and was never affected by annual shoot dieback
Seedling sprout	Seedling originated from seed and affected by shoot dieback, but resprouted from the root collar of the seedling
Root sucker	Seedling arising vertically from lateral root
Coppice	Seedling arising from stumps of cut individual tree
Water sprout	Seedling developed from the base of alive individual tree
Layer	Seedling developed from low hanging lateral branch layers and arising from adventitious buds

The inventory was carried out during the wet season (August 2007) to avoid missing seedlings that shed their leaves or die

back during the dry season. Within each quadrat, the total number of seedlings and live shoots per seedling were recorded. The term 'seedling' here refers to all individual plantlets with a shoot height up to 100 cm, irrespective of the regeneration mechanism (Ky-Dembele et al. 2007). A seedling was considered to be a multi-stemmed individual when it had more than one stem emerging from the base and fulfilled the above size criterion; otherwise it was considered to be a single-stemmed individual. During the inventory, the different regeneration mechanisms were determined by excavating the below-ground root system of each seedling in each quadrat and assessing the number of basal and aerial sprouts. We classified the seedlings into six categories according to their regeneration modes: true seedlings, seedling sprouts, water sprouts, coppices, root suckers and layers (Table 2). We considered true seedlings and seedling sprouts to have originated from sexual regeneration, and coppices, water sprouts, root suckers and layers to have originated from asexual regeneration.

Statistical analysis

The effects of differences in the examined roadside environments on total seedling density, and multi-stemmed and single-stemmed individuals' densities were analyzed with generalized linear models, using penalized quasi-likelihood with Poisson Errors. The relative importance of the different regeneration mechanisms was also analyzed by generalized linear models using penalized quasi-likelihood with Binomial Errors in order to account for the non-normal errors and the inconstancy in variances that are associated with proportional data. Penalized quasi-likelihood estimation was used in order to account for over and under dispersion (Crawley, 2005). Since the roadside environments were nested within road type, the linear (effects) model used to analyze this nested design was:

$$y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \varepsilon_{ijk} \qquad (1)$$

where, y_{ijk} is the kth replicate observation from the jth roadside environment within the ith group of road type; μ is the overall (constant) mean of the response variable; α_i is the effect of the ith road type, which is the difference between the group mean and the overall mean $(\mu_i - \mu)$; $\beta_{j(i)}$ is a random variable with mean zero and a variance of σ_β^2 measuring the variance among roadside environments within road types; and ε_{ijk} is the residual error.

All statistical analyses were performed in the *R* statistical software (R development Core Team 2008). The 'mass' package was used to perform the generalized linear models, utilizing penalized quasi-likelihood estimates. The 'car' package was used to perform the ANOVA, utilizing type III sum of squares for a non-orthogonal design.

Results

Seedling population structure

Total seedling density varied significantly among roadside environments nested within road type ($F_{6, 195}$ = 3.147, p=0.005), but did not between road types ($F_{1, 195}$ = 2.162, p=0.143). Along both paved and unpaved roads, total seedling density was considerably high in the intermediate area, while the lowest seedling density was recorded in the area adjacent to graded and ungraded areas, particularly along the unpaved road (Table 3). With regard to seedling morphology, significant variations were observed among roadside environments for single-stemmed ($F_{6, 195}$ = 5.984, $p < 0.001$) and multi-stemmed ($F_{6, 195}$ = 2.407, p= 0.029) seedling densities, but not between road types ($F_{1, 195}$ = 2.044, p=0.154 and $F_{1, 195}$ = 0.242, p= 0.624 for single- and multi-stemmed seedling density, respectively). Along the paved road, the density of single-stemmed seedlings was lower in the graded area than that in other roadside environments, whereas the density of multi-stemmed seedlings was the lowest in the ungraded area (Table 3). As a whole, the overall density of multi-stemmed seedlings was three times higher than that of single-stemmed seedlings (1.8±0.1 Individuals/m^2 versus 0.6 ±0. 1 Individuals/ m^2).

Table 3. Density (individuals/m^2) of *P. suberosa* seedling (mean ± SE) per quadrat in relation to roadside environments and road types

Item	Graded	Adjacent	Intermediate	Control	Effect (road type)
A. Total seedling density					
Paved road	2.314 ± 0.167	2.475 ± 0.251	3.450 ± 1.048	2.452 ± 0.249	2.612 ± 0.231
Unpaved road	2.336 ± 0.316	1.269 ± 0.197	3.000 ± 0.386	1.910 ± 0.189	2.163 ± 0.152
B. Single-stemmed seedlings					
Paved road	0.358 ± 0.044	0.819 ± 0.124	0.991 ± 0.306	0.914 ± 0.167	0.725 ± 0.081
Unpaved road	0.556 ± 0.118	0.369 ± 0.080	0.886 ± 0.191	0.233 ± 0.035	0.493 ± 0.062
C. Multiple stemmed seedlings					
Paved road	1.956 ± 0.146	1.684 ± 0.176	2.545 ± 0.745	1.538 ± 0.138	1.915 ± 0.166
Unpaved road	1.780 ± 0.229	0.981 ± 0.211	2.109 ± 0.256	1.677 ± 0.178	1.681 ± 0.114

Regeneration mechanisms

Considering both roadside environments and road types together,

all seedlings had been produced asexually. Root suckering strategy was the main regeneration mechanism, accounting for 98.03% of all seedlings, followed by water sprouts (1.32%) and coppices (0.65%). The overall density of root suckers ($F_{1, 195}$ =

1.429, p = 0.233) and water sprouts ($F_{1, 195}$ = 0.315, p = 0.576) did not vary significantly with respect to road type, but a very high significant effect of roadside environment nested within road type on the density of suckers ($F_{6, 195}$ = 3.652, p = 0.002) and water-sprouts ($F_{6, 195}$ = 6.401, $p<$ 0.001) was found. Seedlings recruited by mean of root suckering strategy were more abundant in the intermediate area along both paved and unpaved roads, but less abundant in the area adjacent to the graded area, particularly along the unpaved road. In contrast water sprouts were found in the adjacent area (Table 4). The density of coppice was significantly higher ($F_{1, 195}$ = 9.837, p= 0.002) along unpaved road, compared with paved road ($F_{6, 195}$ = 0.726, p = 0.629). There was overall higher root suckering effectiveness of (5 ± 0) shoots per stump along unpaved road than paved road (3 ± 0); the same was true for coppicing (Table 5). However, no difference in water sprouting effectiveness was found between road types ($F_{1, 195}$ = 0.049, p = 0.825).

Table 4. The density (individuals/m^2) (mean ± SE) per quadrat of suckers, coppice and water sprout of *P. suberosa* in relation to roadside environments and road types

Item	Graded	Adjacent	Intermediate	Control	Effect (road type)
A. Suckers					
Paved road	2.297 ± 0.169	2.456 ± 0.243	3.518 ± 1.041	2.395 ± 0.249	2.604 ± 0.230
Unpaved road	2.280 ± 0.321	1.231 ± 0.231	2.943 ± 0.394	1.860 ± 0.195	2.112 ± 0.155
B. Coppice					
Paved road	0.011 ± 0.009	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.004 ± 0.003
Unpaved road	0.048 ± 0.021	0.031 ± 0.031	0.014 ± 0.010	0.027 ± 0.015	0.030 ± 0.003*
C. Water sprout					
Paved road	0.006 ± 0.004	0.047 ± 0.16	0.018 ± 0.011	0.057 ± 0.023	0.030 ± 0.007
Unpaved road	0.008 ± 0.006	0.094 ± 0.19	0.038 ± 0.013	0.023 ± 0.008	0.035 ± 0.006

Note: Significant effect of road type.

Table 5. The number of shoot per stump of suckers, coppice and water sprout of *P. suberosa* in relation to roadside environments and road types

Item	Graded	Adjacent	Inter-mediate	Control	Effect (road type)
A.Suckers					
Paved road	4 ± 0	3 ± 0	3 ± 0	3 ± 0	3 ± 0
Unpaved road	4 ± 2	5 ± 1	4 ± 0	7 ± 1	5 ± 0*
B. Coppice					
Paved road	0 ± 0	0 ± 0	0 ± 3	0 ± 0	0 ± 0
Unpaved road	3 ± 2	1 ± 1	2 ± 1	2 ± 1	2 ± 1*
C. Water sprout					
Paved road	0 ± 0	2 ± 1	1 ± 0	3 ± 1	1 ± 0
Unpaved road	0 ± 0	4 ± 1	4 ± 2	2 ± 1	2 ± 1

Note: * Significant effect of road type.

Discussion

The results presented herein show that seedling density of *P. suberosa* varied substantially among roadside environments nested within road type. Although the disturbance from roadworks usually exceeds that of any natural disturbance regime, in terms of both intensity and frequency, and may eventually lead to local extinctions of many roadside plant species (Lugo and Gucinski 2000), this study has provided evidence that *P. suberosa* is a disturbance-tolerant species which can proliferate in a roadside environment. The ultimate criterion for survival is the ability to recruit new seedlings and thus maintain a population (Peters 1997). The more efficient a strategy is in fulfilling this criterion, the longer the population will remain established. The results of the present study indicate that soil disturbance cause by road construction did not negatively affect *P. suberosa* seedling recruitment ability and persistence. Similar studies have shown that anthropogenic soil disturbance promotes the recruitment of *Acacia* populations along roadsides in Australia (Spooner et al. 2004; Spooner 2005). Although the disturbance of soil by roadwork activities is an important process in triggering recruitment of seedlings, the scale of the response depends on the severity of the disturbance. The present study indicates that an intermediate level of disturbance caused by grading nested within road type, was most favorable for seedling recruitment. This could be explained by the fact that at the intermediate level of disturbance there is less excavation compared with the other graded areas, and root material which can become divided into several parts by the grading process, is then deposited, together with other debris and humus creating a micro-environment. The rough soil surface, the grading depth, and newly established environmental conditions, may therefore provide suitable niches, in which regeneration material of *P. suberosa* can lodge, take root and emerge.

The fact that no difference in seedling density was found between paved and unpaved roads suggested that *P. suberosa* must be adapted to habitat dissected by both types of road and that it is indifferent to the ecological impacts of paved and unpaved construction. Unpaved road construction does not involve the high level of disturbance caused by the construction of permanent paved roads. A wide clearing is thought to enhance the colonization process by reducing competition for water and nutrients, opening up more growing space, and increasing the availability of light at ground level (Forman 2004; Karim and Mallik 2008), all of which are likely to affect the composition of the *P. suberosa* seedling communities. It should also be noted that the competition for light, water and nutrients might be strongly influ-

enced by the initial vegetation density. For example, if vegetation density is high before clearing a strip for construction, the opening of a wide clearing along the road could have a marked effect. However, since the distribution of the woody component of most savanna-woodlands is scattered, this may counterbalance any initial positive effect of increased light availability.

The density of multi-stemmed individuals appeared to be higher in all roadside environments, compared to the density of single-stemmed individuals. This could be ascribed to survival strategies in response to disturbance in the initial phase of seedling growth. Indeed, most species have been found to mitigate the effects of disturbance by physiological and morphological changes (Larcher 1995). In addition, in the graded areas seedling populations may also have been shaped by disturbance from fire or grazing, which is common along roadsides (personal observation). Many species survive by sprouting from dormant buds on the roots or from adventitious buds on lateral roots, stems and old shoots (Kozlowski 2002).

The severity of disturbance often determines the regeneration mechanism employed by plants during recovery (Bellingham 2000). In the present study, the most obvious evidence of physical damage to roadside plants from road workings and earth movement was the complete removal of above-ground biomass as a result of grading, leaving only stumps and damaged roots. The abundant regeneration of *P. suberosa* by root suckering in all roadside environments, along both paved and unpaved roads, is similar to the findings of previous studies, which have indicated *P. suberosa* to be a facultative seed producer, regenerating primarily by root-suckers, with little regeneration occurring from seed (Bationo 1996; Bellefontaine 2005). The lack of true seedlings observed in the present study may be explained by the low viability of seeds of such species (Dayamba et al. 2008). It could also be ascribed to the prevention of seed germination and seedling establishment as a result of inappropriate substrate and inadequate moisture conditions in roadside habitats caused by the road works. Although no data were collected on the status of soil seed banks prior to, and after, soils were disturbed by roadworks, the availability of viable soil-stored seed is generally low; it varies according to the duration, frequency and intensity of the disturbance (Teketay 1997; Luzuriaga et al. 2005). Furthermore, although various species can germinate at depths of up to 90 mm (Cavanagh, 1980), the depth to which any seed might have been buried by soil movement during roadworks, may have affected the germination success of *P. suberosa*.

In agreement with the findings of Ky-Dembele et al. (2007), the contribution of coppices and water sprouts to regeneration was poor, compared with root suckering. Damaged roots generally sprout vigorously, which greatly aids the ability of this species to colonize disturbed areas. Root suckering is a common response in woody plants subjected to severe disturbance regimes that destroy most or all of the above-ground biomass (Hodgkinson 1998; Bellefontaine et al. 2000; Belem et al. 2008) and it appears to be the primary regeneration strategy of this species. Similar studies have shown that plants can re-sprout after repeated damage from heavy machinery (Gibson et al.

2004). These results suggest that in areas affected by roadwork activities, known as the "road effect zone" (Forman et al. 2004), soil disturbance by grading is an important process impacting roadside *P. suberosa* populations. In addition, changes in the environment of the road effect zone during road operation may also have affected roadside *P. suberosa* populations. Elevated light intensities and temperatures, differences in shelter, and the increased moisture stress that occurs at the edge of roads, have all been found to affect tree saplings in many roadside environments (Nabe-Nielsen et al. 2007; Goosem 2007). The finding in the present study that only vegetatively propagated seedlings were abundant suggests that *P. suberosa* has a competitive advantage in colonizing roadside environments, thereby enhancing its reproductive fitness.

Conclusion

Soil disturbance regimes resulting from roadwork activities are often considered to pose a major threat to plants in roadside environments. However, this study demonstrates that an intermediate level of soil disturbance from grading along paved and unpaved roads may stimulate *P. suberosa* regeneration by root suckering. Road type (paved and unpaved) did not affect seedling density, but was a highly significant variable in relation to the coppicing ability of *P. suberosa* populations in roadside sites. Two management implications of roadside vegetation are supported by these findings. First, road agencies can use similar techniques to manage roadside vegetation along paved and unpaved roads, since regeneration conditions are similar in both road environments. Secondly, since an intermediate level of disturbance from grading appears to enhance the regeneration of *P. suberosa*, minimizing the width of roadworks and soil disturbance should be considered by road management agencies in order to reduce the costs of both establishment and subsequent maintenance of roadside vegetation.

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